CORN GRAIN QUALITY IN INTEGRATED CROP-LIVESTOCK-FOREST SYSTEMS: HOW DISTANCE OF TREE LINES AFFECTS DAMAGE AND BULK DENSITY OF GRAINS

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ABSTRACT
The objective of this study is to evaluate how the distance between the corn planting rows intercropped with *Urochloa* cultivars and the tree stand line (eucalyptus) affects grain bulk density and percentage of damaged grains. The treatments consisted of the corn in two cropping systems, i.e., between eucalyptus stands (integrated crop-livestock-forestry-ICLF) and in full sun intercropped with the *Urochloa*, in the planting line three years after the establishment of eucalyptus trees (2013/2014 harvest). Corn samples in two cropping systems were submitted to the physical classification according to the methodology described in the Technical Regulation of Corn, volumetric weight (bulk density) of grains (kg m^{-3}) and moisture content. In the ICLF system, grain bulk density was negatively affected by tree growth, and this parameter increased with greater distance to the tree stand line, and on the other hand, the total damaged grains show the opposite tendency, with a reduction in the total percentage of damaged grains with the increase in the distance from the tree stand lines. The growth of trees in the harvests after the third year of the establishment of the ICLF system increases losses in grain bulk density and total damage of corn grains.
Key words: *Zea mays*; grain damage; intercropping system

INTRODUCTION

Intensive production systems such as integrated crop-livestock-forestry (ICLF) seek to improve the conditions of degraded areas by including different species, in a synergistic manner, to recover and maintain productivity (BALBINO et al., 2011). They offer an alternative for regions where the use of pasture predominates as a way of producing meat and milk and which are suffering from degradation of pastures, for example, the Brazilian Cerrado region. This system has other advantages, such as more rational use of inputs, machines, and labor on farms, in addition to diversification of production and the cash flow of producers (MACEDO, 2009).

The ICLF system with intercropping of corn and *Urochloa* cultivars is recommended for regions with agroclimatic aptitude for corn culture, and specific financing incentives should be provided by government programs, such as the ABC Plan (Low Carbon Agriculture) (GONTIJO NETO et al., 2014). The intercropping of eucalyptus, corn, and *Urochloa* has become one of the strategies to maximize the sustainability of livestock in different regions, including the Brazilian Cerrado, where livestock activity predominates as the main source of income for producers. This intercropping has been studied in long-term experimental areas, such as in the experimental field of Embrapa Maize & Sorghum, in Sete Lagoas/MG, with a focus on evaluations grain, forage and wood production and their sustainability (CAMPANHA et al., 2020; MOREIRA et al., 2018; SIMÃO et al., 2018; WENDLING et al., 2014).

The quality evaluations of grains produced in the ICLF systems are still little explored, especially when it comes to assessing the influence of the impact of trees, for example eucalyptus with 3 years of planting, on the shade and of the plants of the annual crops grown between the tree lines. Studies evaluating the presence of fungi in soybean grains, in ICLF systems, point out that these systems did not negatively affect the quality of soybean grains (WRUCK; MAGALHÃES; HENNING, 2019). Initial quality measurements of corn grains produced in the ICLF system compared to grains produced in the conventional system (monocultures) point out qualitative parameters compatible with the tolerance limits established in the current quality and identity standards established for corn (BRASIL, 2011; PIMENTEL et al., 2012), without damage to the quality of grains produced in this system.

However, in field observations, there was a certain influence of the tree line on the closest plants, whether owing to shading or even competition (SIMÃO et al., 2018), which can directly reflect on the quality of the grains produced, and negatively impacts producers, especially nowadays with comparatively higher prices of grains such as corn (CEPEA/ESALQ/USP, 2021). These work tests the hypothesis that the tree stand line impacts grain bulk density and percentage of total damage; thus, the objective of this study is to evaluate how the distance between the corn planting rows intercropped with *Urochloa* and the tree stand line (eucalyptus) affects grain bulk density and percentage of damaged grains.

MATERIAL AND METHODS

The experiment was conducted in the experimental area of Embrapa Maize & Sorghum, in Sete Lagoas/MG (19° 29'106''S, 44° 10'773''W, at an altitude of 708 m). The climate of the region is of the Aw type, according to Köppen's classification, with dry season from May to October and wet season from November to April. The soil is classified as a typical dystrophic Red Latosol (LVd), with clayey texture, according to the Brazilian Soil Classification System (SANTOS et al., 2013), with smooth undulating relief, under Cerrado vegetation. The chemical attributes soil of the experimental area were described by Moreira et al. (2018).

On October 24, 2011, the cultivar GG100 of eucalyptus (*Eucalyptus urophylla* S.T. Blake) was planted in six rows, with a length of 100 m, in the spatial arrangement of 15x2 m, totaling 333.3 trees per hectare. Clonal seedlings were sown in the furrow and fertilized with 200 kg ha^{-1} single superphosphate, plus 120 g $N\text{-}P_2O_5\text{-}K_2O$ (06-30-06) per plant, with 0.5% B and 1.5% Zn, half applied on each side of the hole, at 15 to 20 cm from the seedling. Cover fertilization was performed within the crown projection area with 120 g $N\text{-}P_2O_5\text{-}K_2O$ (20-00-20) per plant one week after planting and with 200 g per plant in November 2012. Then, in February 2013, 15 g boric acid was applied per plant within the crown projection area of each tree. In September 2013, the trees were stripped to 1/3 of their height. In November 2013, the eucalyptus stands presented mean heights of 10.3 m.

A no-tillage seeder-fertilizer was used to sow AG 8088VT PRO corn seeds simultaneously with 4 kg ha^{-1} viable pure seeds of forage grass in the same planting row, both between the eucalyptus stands and in the area with full sun. To this end, three rows were spaced 0.70 m apart, keeping 1 m between the first row of corn and forage and the eucalyptus tree stand (tree component), up to a final stand of 68,000 plants per hectare. The area planted with corn intercropped with forage and eucalyptus was of 0.867 ha. The corn seeds were treated with 135 g ha^{-1} imidacloprid + 186 g ha^{-1} thiodicarb. Fertilization at the time of sowing consisted of 400 kg ha^{-1} $N\text{-}P_2O_5\text{-}K_2O$ (08-28-16), and, when corn reached the V6–V7 phenological stage, the cover crop was fertilized with 250 kg ha^{-1} urea (Souza & Lobato, 2004). The seeds of the grasses were treated with 5 g ha^{-1} fipronil.

The control of invasive plants was carried out between 15 and 21 days after sowing with the application of 1.5 kg ha^{-1} atrazine and 10 g ha^{-1} nicossulfuron to slow down the development of the forage. The experimental design was completely randomized, in 2x5, with four replicates. The treatments consisted of the hierarchical factors: corn in two cropping systems (plot), i.e., between eucalyptus stands (ICLF) and in full sun intercropped with the forage grasses *U. brizantha* 'Marandu', *U. brizantha* 'Xaraés', *U. brizantha* 'Piatã', *U. ruziziensis*, and *U. decumbens* 'Basilisk' in the planting row (subplot) three years after the establishment of eucalyptus trees (2013/2014 harvest). Samplings were performed at 2013/2014 harvest when corn grains reached around 14% moisture. The useful experimental plot in the ICLF system consisted of 2.0x4.9-m (9.8 m^2) areas, perpendicular to the rows of tree, in which 2 linear meters were evaluated in the first (1.0 m), third (2.4 m), fifth (3.8 m), seventh (5.2 m) and ninth (6.6 m) corn rows.

In the full sun system, corn intercropping was evaluated in a useable area of 1.4 m^2 (2 m length x 0.7 m width), in the direction of the corn planting row. After mechanical threshing, homogenization and reduction of samples from each plot were performed, and grain bulk density (kg m^{-3}) was determined using a kit for determining the volumetric weight (bulk density) of grains (Gehaka®) with capacity of one liter of grains. Moisture content was also initially determined, following the recommendations of the Seed Analysis Rules (BRASIL, 2009).

The physical classification was performed according to the methodology described in the Technical Regulation of Corn (IN 60/2011), which defines the identity and quality for purposes of classification into group, class and type (BRASIL, 2011). The parameters analyzed in the classification process were (%): broken grains (5mm and 3mm sieves), foreign matter and impurities, insect damage, heat damage, immature grains, fermented (cob rot damage), germinated, plastered, mold damage and total of damaged grains, which represents the sum of the seven classes of defects described.

Grain bulk density and total of damaged grains (%) were submitted to analysis of variance. The relationships between grain bulk density and total of damaged grains and the distance to the tree stand line (m) were subjected to regression analysis, in addition to correlation analysis.

RESULTS AND DISCUSSIONS

The effect of distance to the tree stand line was significant in the variation of grain bulk density ($F_{4;16}$ = 39.44; P <0.0001), but non-significant between the five different stands ($F_{4;16}$ = 1.62; P <0.1790) and their interactions ($F_{4;16}$ = 0.69; P <0.7916) for the evaluated parameters. It was found that, in the ICLF system, grain bulk density was negatively affected by tree growth, and this parameter increased with greater distance to the tree stand line (Figure 1).

Linear response between grain bulk density and the distance to the tree stand line was significant ($F_{1,24}$ = 65.76; P < 0.0001) (Figure 1). Simão et al. (2018) also found an effect on the distance between the tree stand line and corn grain yield, with up to 30.2% reduction. These authors reported a reduction in the incidence of photosynthetically active radiation among the ranks, directly reducing forage and maize grains yields in the intercropping system with *U. brizantha*. The arboreal component in the Integrated Crop-Livestock-Forest system, especially in 3-year-old eucalyptus trees (above 10.3 m in height), alters the environment in the sub-forest, reducing the incidence of radiation in corn plants, which are highly dependent on solar radiation for their full development.

The distance to the tree stands lines had a significant effect on the variation of total damaged grains ($F_{4;16}$ = 28.86; P <0.0001), but it was not significant between the five different stands ($F_{4;16}$ = 5.23; P <0.0100) and their interactions ($F_{4;16}$ = 1.42; P <0.1579) for the evaluated parameters. The ICLF system affected the total damaged grains near the tree lines, with a reduction of the damaged grains with increased distance from the tree stand line (Figure 2). The total percentage of damaged grains is represented by the sum of the main defects identified in the samples, being the sum of insect damage, heat damage, immature grains, fermented (cob rot damage), germinated, plastered and mold damage. The predominant damages observed in the samples were heat damage, fermented, mold damage and immature grains, respectively.

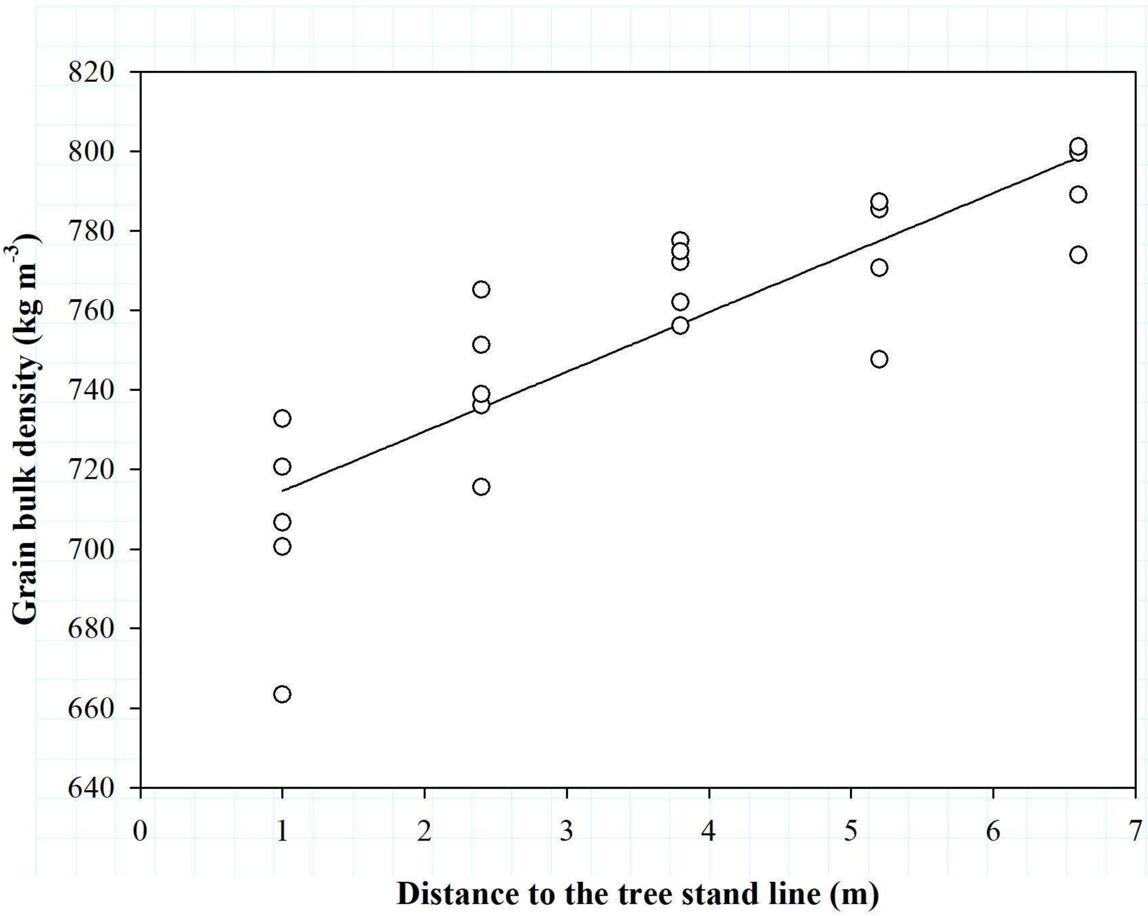

Figure 1. Influence of distance to the tree stand line (m) on bulk density of corn grains (kg m^{-3}). Curve was fit using regression analyses ($y = 699.59 + 14.99x$; $r^2 = 0.86$).

There was a significant linear response between total amount of damaged grains and distance to the tree stand line ($F_{1,24} = 54.47$; $P < 0.0001$) (Figure 2). This finding suggests that the total amount of damaged grains was reduced when the distance to the tree stand line was increased; total damage ranged between 1.5 to 3.0% in the first line after the tree stand line, and less than 1.0% in the furthest lines (Figure 2).

There was a reduction in grain bulk density in the ICLF system compared with full sun in the first two rows, with a mean reduction of 11.4 and 6.78% in weight, respectively. For the total amount of damaged grains, there was an increase by 84.6 and 83.3% in the ICLF system compared with full sun in the first two lines, respectively. It was found that grain bulk density increased with increasing distance to the tree stand line, and there was a positive and significant correlation (Table 1). The total damaged grains decrease with increasing distance to the tree stand line, and there was a negative and significant correlation (Table 1). The relationship between grain bulk density and total damaged grains was a negative and significant correlation (Table 1). Our results with positive and significant correlation between grain bulk density and distance to the tree stand line were corroborate in the work of Simão et al. (2018), who found significant positive correlations between corn grain yield and solar radiation level.

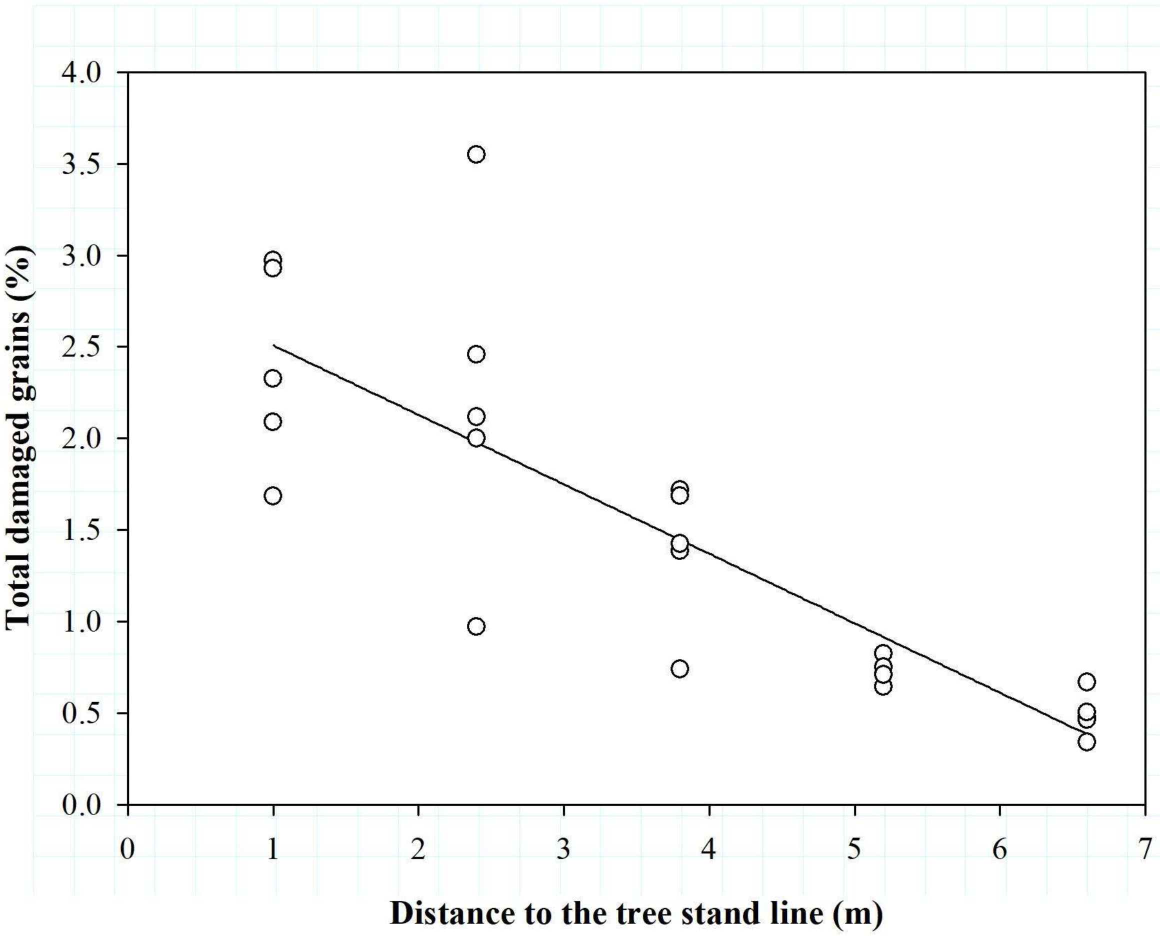

Figure 2. Influence of distance from trees (m) on total damage corn grains (%). Curve was fit using regression analyses (y = 2.89 - 0,38x; r^2 = 0.84).

Considering the Normative Instruction that establishes the qualitative parameters for classification of corn into types (BRASIL, 2011), the ICLF system presents a quality of grains similar to the one presented in the full sun system (monoculture), with percentages of damaged ones that allow framing in Type 1. Grains harvested in the rows closest to the tree stand showed percentages of damaged ones that fit the grains into Type 2 or 3. Thus, the producer must be attentive to the cultivation of corn in ICLF systems with larger trees, as in this experiment where the eucalyptus reached 10.3 meters in height, on average.

Table 1. Pearson's correlation coefficients between grain bulk density, total damaged grains and distance to the tree stand line.

	Grain bulk density	Total damaged grains	Distance to the tree stand line
Grain bulk density	1.00	-0.68888*	0.86073*
Total damaged grains		1.00	-0.83886*
Distance to the tree stand line			1.00

*Significant ($p < 0.01$) by the Pearson test.

CONCLUSIONS

The tree stand line negatively impacts grain bulk density and increases the percentage of total damage, on the rows close to the stand tree line. The growth of trees in the harvests after the third year of the establishment of the ICLF system increases losses in grain bulk density and total damage of corn grains.

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